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Long Duration Sorbent Testbed

David F. Howard¹, James C. Knox², David A. Long³
NASA Marshall Space Flight Center, Huntsville, AL 35812

Lee Miller⁴, Gregory Cmaric⁵
Jacobs Technology, Marshall Space Flight Center, Huntsville, AL 35812

and

John Thomas⁶
Ratheon, Marshall Space Flight Center, Huntsville, AL 35812

The Long Duration Sorbent Testbed (LDST) is a flight experiment demonstration designed to expose current and future candidate carbon dioxide removal system sorbents to an actual crewed space cabin environment to assess and compare sorption working capacity degradation resulting from long term operation. An analysis of sorbent materials returned to Earth after approximately one year of operation in the International Space Station's (ISS) Carbon Dioxide Removal Assembly (CDRA) indicated as much as a 70% loss of working capacity of the silica gel desiccant material at the extreme system inlet location, with a gradient of capacity loss down the bed. The primary science objective is to assess the degradation of potential sorbents for exploration class missions and ISS upgrades when operated in a true crewed space cabin environment. A secondary objective is to compare degradation of flight test to a ground test unit with contaminant dosing to determine applicability of ground testing.

Nomenclature

<i>4BMS</i>	=	Four Bed Molecular Sieve
<i>CO₂</i>	=	Carbon Dioxide
<i>CDRA</i>	=	Carbon Dioxide Removal Assembly
<i>EDU</i>	=	Engineering Design Unit
<i>ISS</i>	=	International Space Station
<i>LED</i>	=	Light Emitting Diode
<i>LDST</i>	=	Long Duration Sorbent Testbed
<i>RTD</i>	=	Resistance Thermal Detector
<i>SOA</i>	=	State of the Art

I. Introduction

THE challenges of extending human space flight missions to destinations beyond low Earth orbit, such as Mars, will include improving the performance and long term reliability of the Carbon Dioxide (CO₂) removal system

¹ Project Engineering Manager, International Space Station Office, MSFC, AL 35812

² CO₂ Removal Lead Engineer, ECLSS Development and Test Branch, MSFC, AL 35812.

³ Lead Engineer, ECLSS Development and Test Branch MSFC, AL 35812.

⁴ Design and Test Engineer, ECLSS Development and Test Branch, MSFC, AL 35812

⁵ Chemical Engineer, ECLSS Development and Test Branch, MSFC, AL 35812

⁶ Design Engineer, ECLSS Development and Test Branch, MSFC, AL 35812

beyond the current State of the Art (SOA) that currently is used on the International Space Station (ISS). Part of the improvement activities include identifying or development better sorbent materials that offer improved performance characteristics to reduce system mass and meet ever more demanding requirements to reduce atmospheric CO₂ levels, and to better retain structural integrity to minimize material attrition and improve reliability. Several sorbents have been identified that possess improved characteristics and are under consideration for use in future systems for exploration missions. One characteristic of major concern is the ability to retain sorption capacity in the presence of trace airborne contaminants in the siloxane family. Because the makeup of the contaminants that have shown to cause performance degradation in sorbents are not fully defined or understood, it is necessary to perform a flight experiment.

II. Rationale for Experiment

Sorbent materials operating within the CDRA onboard the ISS have experienced significant performance degradation over time. This performance degradation is found to be unique to prolonged operation within a closed cabin environment as is experienced on the ISS. Evidence indicates the degradation is caused by the accumulation of airborne trace contaminants, primarily siloxanes, on the sorbents. Long duration testing on the ground so far has not replicated the degradation found by sample analysis of materials returned from orbit, indicating the responsible contaminants are not present in typical process air used in ground testing. The contaminant variants and quantities are not sufficiently characterized to confidently simulate in a ground test. Figure 1 below demonstrates the extent of working capacity degradation of water on silica gel material extracted from an ISS Carbon Dioxide Removal Assembly (CDRA) desiccant bed after approximately one year of operation on orbit. The data in Figure 1 demonstrates that the highest percentage of working capacity loss happens at locations closest to the bed inlet, and capacity loss effects are less with sorbents deeper into the bed. This gradient of working capacity degradation is an indication that the contaminants penetrate through the bed over time, and the longer the system operates, the deeper the contaminants will penetrate the bed. Also shown in Figure 1 is working capacity of materials doped with D5 siloxane to demonstrate working capacity loss in the presence of a known siloxane onboard the ISS.

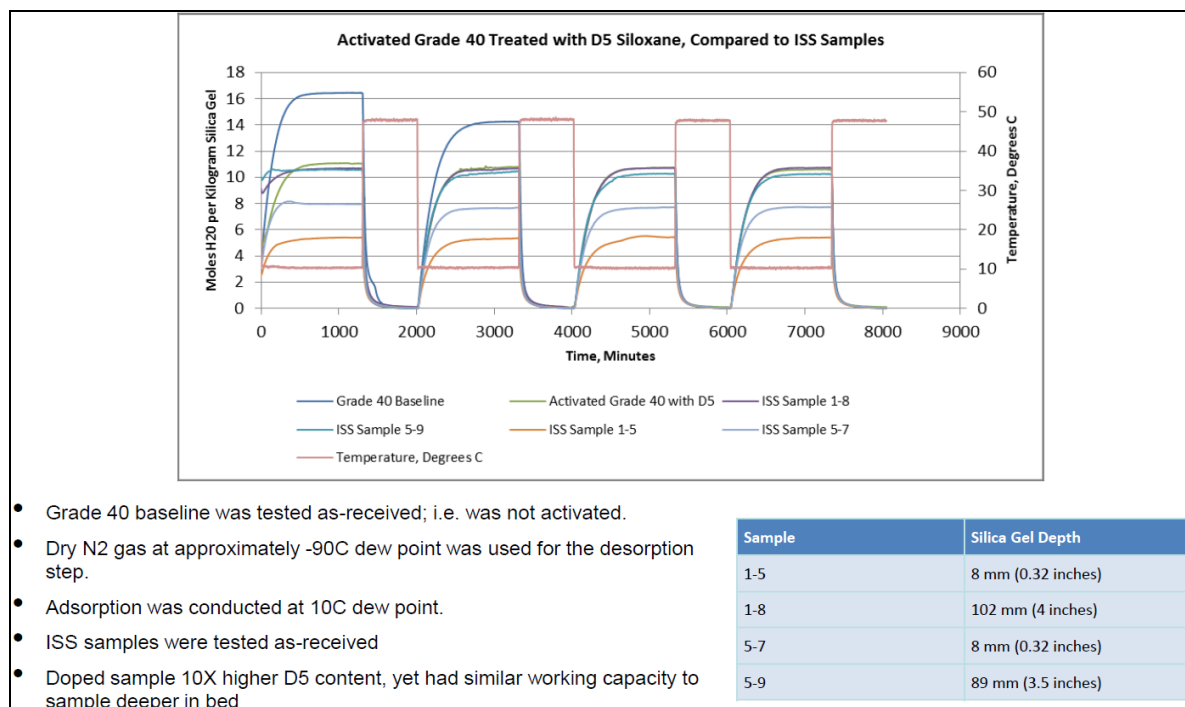


Figure 1. Thermogravimetric Analysis Results. Activated Grade 40 silica gel treated with siloxane compared to ISS samples.

III. Streamlined and Accelerated Development Process

The Long Duration Sorbent Testbed (LDST) was approved under an experimental fast track to flight process, in which the project was relieved of Quality Assurance oversight and processes in exchange for shortened development and build schedule and reduced budget. This approach is limited to NASA center institutional processes only and does not provide relief to payload integration and safety processes. This enabled the design, manufacturing, quality assurance, and technical integration elements of the payload development to be performed within the Principal Investigator's organization. By streamlining the development process, considerable time and budget savings were realized. The conditions for a project to qualify for the streamline process is that the payload does not provide any vehicle needed function, and that if it fails it can not cause any harm to vehicle systems or crew.

IV. Design

The LDST consists of two 4-bed loops, each loop designed to expose selected sorbent materials to cyclic conditions similar to those experienced in the ISS CDRA. Each loop contains two desiccant beds and two CO₂ removal sorbent beds to complete a Four Bed Molecular Sieve (4BMS) process. One loop contains materials used in the existing ISS CDRA as a control sample, with the other loop containing alternate sorbents that are under consideration for a next generation system. Each LDST is less than 1/100 scale of the actual CDRA system, and all CO₂ scrubbed from the ISS cabin air is returned to the cabin during desorption for simplicity, therefore there is no net removal of CO₂ from the cabin by the payload. The system schematic is shown in Figure 2 below. In addition to the beds, the system contains various valves, pumps, filters, sensors, and controls necessary to continually cycle each bed through alternating adsorption and thermal desorption modes.

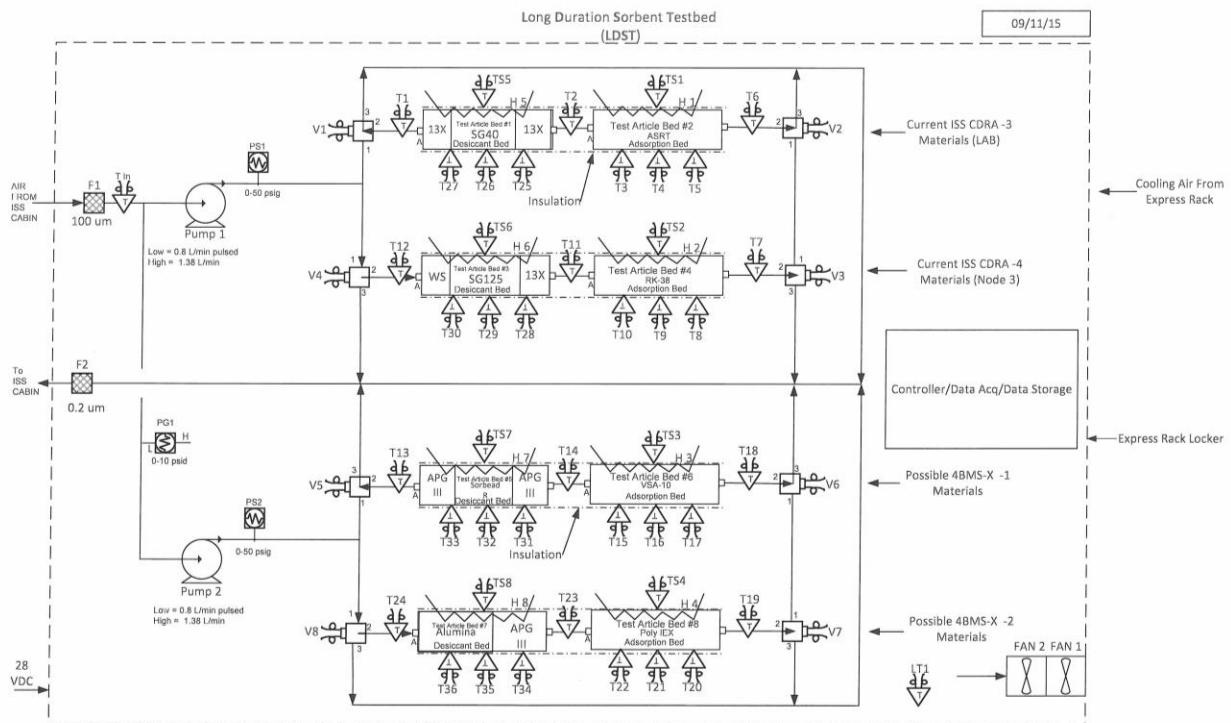


Figure 2. LDST Component Schematic

A. Bed Design

The construction of each LDST bed is identical other than the contained sorbent material. The cross section of the beds are equivalent to a single heater core channel within the ISS CDRA in order to match thermal and flow characteristics. The flow rate is set so that the velocity is equivalent to that in the ISS CDRA. Containment of the

sorbent media is also designed to replicate that of the ISS CDRA, with a 10 psi spring loaded baffle plate at one end against a fixed baffle plate at the other. Each baffle plate includes an o-ring seal to the bed's inner diameter to prevent a sorbent leak path. Each of the baffle plates are also covered with double layered wire mesh filter to prevent liberation of fines. The bed housing is constructed of an Invar tube because of its low coefficient of thermal expansion to prevent crushing the sorbent media from thermal cycles. A detail of the bed assembly is shown in Figure 3.

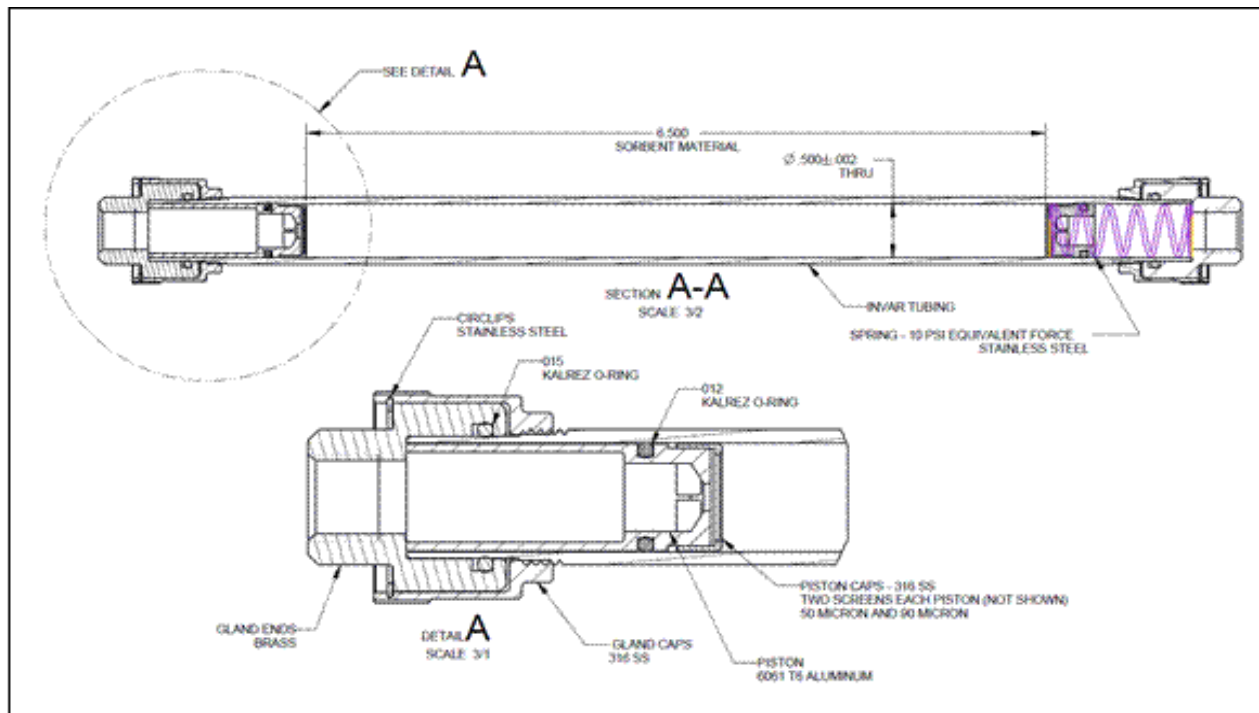


Figure 3. LDST Bed Assembly Details

The bed housings are each wrapped with a 40W electrical resistance heating element and are fitted with four surface mounted RTD's to provide feedback for temperature controls and thermal protection shutdown in the event of an over-temp occurrence. The entire bed is wrapped in insulation to contain heat to the bed. Figure 4 shows an assembled bed prior to adding the insulation.



Figure 4. LDST bed with heater

B. Assembly

All components of the LDST are tightly packaged to minimize heat loss and to enable the entire testbed to fit inside a single EXPRESS Rack locker. A top level assembly drawing that demonstrates relative component locations is provided in Figure 5. In addition to the functional components previously mentioned, the assembly also contains fans at the rear of the assembly for cooling using ISS avionics air that cycles continuously through the assembly, and filters to protect debris from entering the system inlet and to prevent release of sorbent debris into the cabin atmosphere.

#	QTY	DESCRIPTION
1	1	STRUCTURE ASSEMBLY
2	1	TEST ARTICLE NETWORK ASM
3	1	EXPRESS LOCKER
4	2	PROCESS PUMP
5	1	INLET FILTER
6	2	COOLING FAN
7	1	OUTLET FILTER
8	2	PRESSURE SENSOR
9	1	POWER SWITCH
10	1	CIRCUIT BREAKER
11	1	POWER CONNECTOR
12	1	DELTA PRESSURE SENSOR
13	1	CONTROLLER
14	1	LED TOGGLE SWITCH
15	1	CYCLE CONTROLLER ASSEMBLY
16	1	AIR DIVERTER 1
17	1	AIR DIVERTER 2
18	1	LED CONTROL PANEL

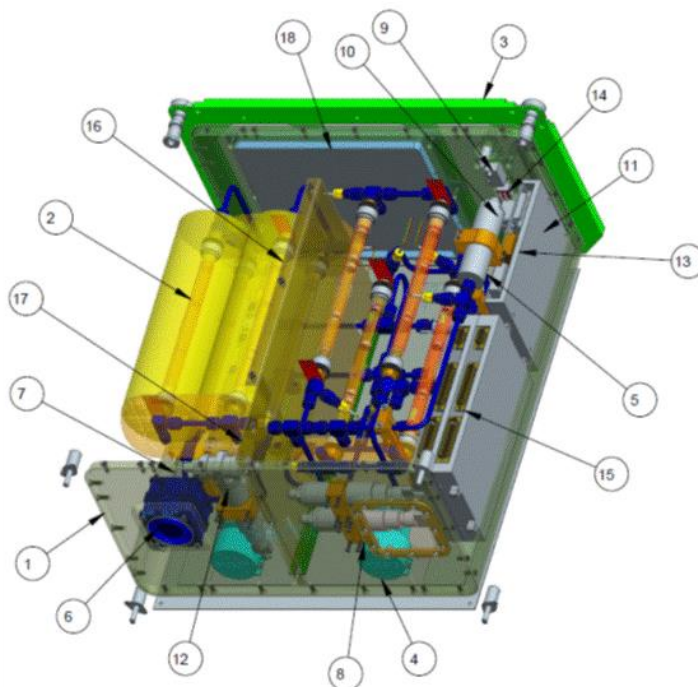


Figure 5. LDST Assembly

C. Interface and Operations

Upon arrival to the ISS, the LDST EXPRESS rack locker will be installed into the designated EXPRESS rack inside the Japanese Experiment Module. Once the locker is installed in the rack, the power cable will be installed from the Rack panel to the Locker using the supplied cable. Power will be initiated to the locker via a ground command and the LDST will begin autonomous operations. The autonomous operations consist of pre-startup conditioning, followed by nominal operational cycling.

The LDST payload uses minimal EXPRESS interface per the following:

- 28V from EXPRESS rack
- AAA cooling (enables use of EXPRESS fire detection)
- Periodic LED display status checks (panel layout is shown in Figure 5)
- Data stored internally on microchip

The LDST operations draws process air from and returns to cabin atmosphere (1.4 lpm). Operational mode and health can be monitored by the front panel LED display (figure 5). LDST will use control software to cycle through the various operating modes, and will provide commands to heaters and pumps based on feedback sensors to achieve the desired set-points.

The operational status of the LDST can be evaluated by a series of LED indicators on the front panel of the payload. Under nominal operations, only LED's that indicate the system is operating nominally or off-nominally will be activated. The crew will monitor the status once a week to verify the system is operating nominally. If for some reason the systems nominal operations are disrupted, an amber light will illuminate. The investigating crew

LONG DURATION SORBENT TESTBED							
HEALTH AND STATUS							
SYSTEM		ON		MEMORY FULL		ERROR	
		CPU	FAN1			CPU	FAN1
		FAN2				FAN2	
						LT1	
CHANNEL 1	P1			1-PS0		CPU1	
	H1			1-PS1		PS1	
	H2			1-PS2		TS1	
	V1			1-C1		TS2	
	V2			1-C2		H1	
	V3			1-C3		H2	
	V4			1-C4			
CHANNEL 2	P2			2-PS0		CPU2	
	H3			2-PS1		PS2	
	H4			2-PS2		TS3	
	V5			2-C1		TS4	
	V6			2-C2		H3	
	V7			2-C3		H4	
	V8			2-C4			

Figure 6: LED status panel

member would then turn the LED status panel switch on to activate the full set of LED's, take a picture and send to the ground, and system diagnosis will be performed by appropriate staff to determine follow on activities. A diagram of the LED panel that provides operational status is shown in Figure 6.

D. Flight Article

At the time of this paper submission, the build of the flight hardware is completed and is awaiting launch on Space-X 9 for transport to the ISS. All verification testing has been completed and the hardware is packaged and ready for on-dock delivery. Figure 7 shows the flight article internal components after wiring was completed with box panels not attached. Figure 8 shows the LDST installed in a single EXPRESS Rack locker in the configuration it will be launched to the ISS with all relevant labels installed. As can be seen, the LDST was rated as a Toxicology Hazard Level 1. This rating was based on the possibility for sorbent materials to breakdown and produce dust that could cause minor eye or upper respiratory irritant.

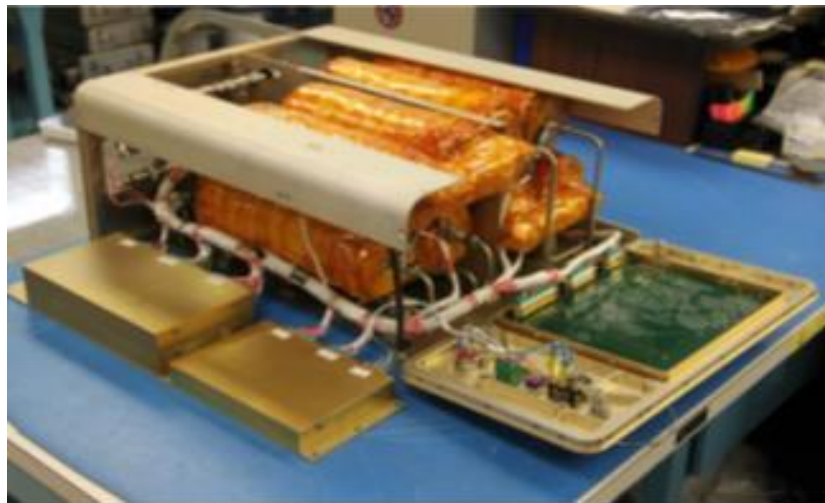


Figure 7. LDST with panels removed showing internal components

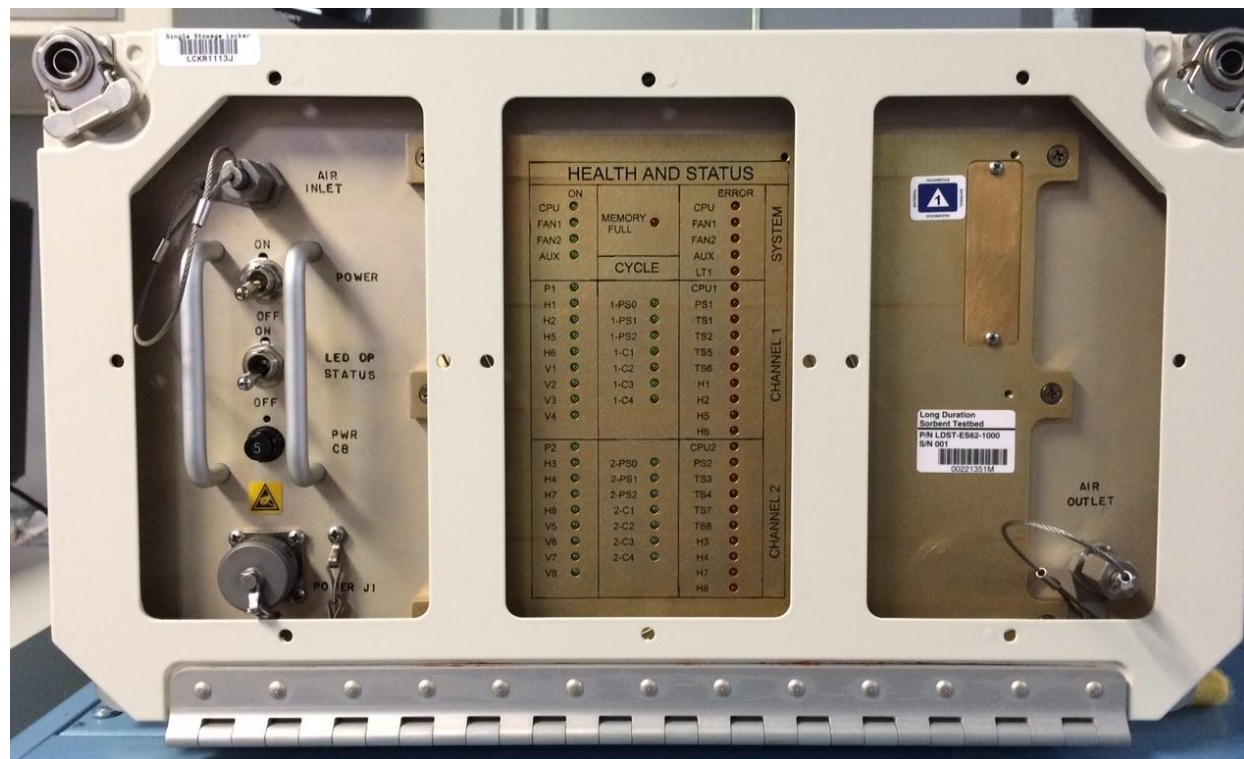


Figure 8. LDST experiment payload

V. Ground Testing

In parallel to the flight experiment, a ground test will be conducted using the LDST Engineering Development Unit (EDU) at the Johnson Space Center (JSC). The EDU is functionally identical to the flight unit, but it is outfitted with sample ports on each of the beds so that samples can be pulled at various locations for analysis. For ground testing, the inlet air will be conditioned to appropriate levels of primary constituents (humidity, CO₂, etc.) and injected with a matrix of contaminants suspected of degrading sorbent capacity. Regular analysis will be performed on the samples to provide near real time performance data on the EDU to identify performance degradation. After the flight experiment is completed and the flight experiment returned to Earth, a comparison of data between the ground and flight testing will be conducted to assess the accuracy of ground testing with respect to working capacity degradation and determine if future tests can be performed by ground testing alone.

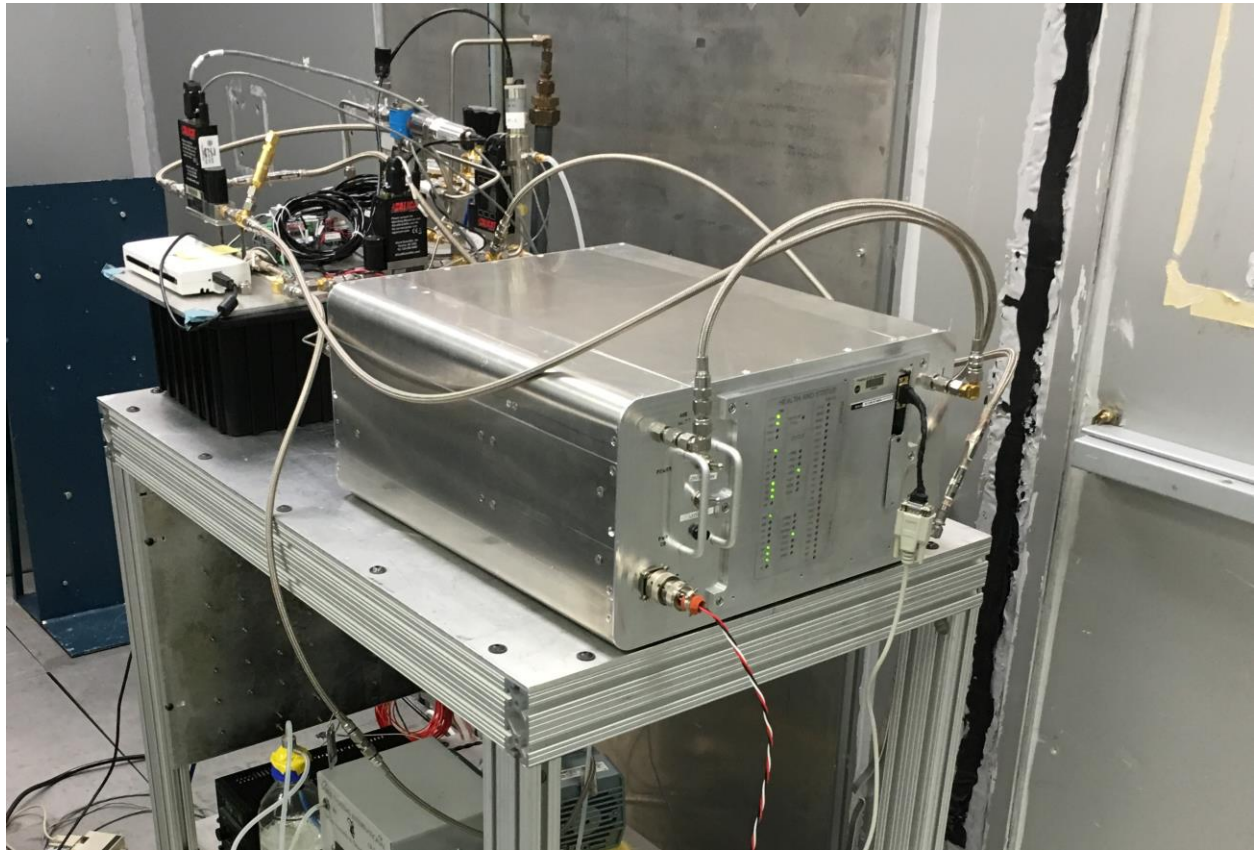


Figure 9. LDST EDU to be used for ground testing

VI. Conclusion

The LDST flight experiment development and build is complete, and is on schedule to launch on board Space-X 9 to the ISS in June 2016. From conception to completion, the LDST flight experiment was readied for flight in about a year using a streamlined development effort by bringing many of the design, fabrication, and quality assurance functions internal to the Principal Investigator's organization. The LDST is planned to operate autonomously for a one year duration with minimal crew interface. Outside of periodic checks and simple filter changes, the crew should not need to interface with the payload unless an off nominal condition occurs. When the experiment is completed, the payload will be returned to Earth and analyzed on the ground to quantify how well the candidate sorbent materials maintained ability to function after long term operation in a relevant closed cabin environment. This data will play a factor for selecting materials for reliable high performing CO₂ removal systems necessary for human explorations to reach beyond low Earth orbit to future destinations.

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